High Performance Opto-Mechanical and Structural Components in C/SiC-Technology (Short Carbon Fibre Reinforced Silicon Carbide)

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Overview

- C/SiC Material Technology
- Material Properties
- Applications
- Design Potential
  - Large Pieces
  - Coatings
  - A-thermal Structures
  - Mirror Design Concepts
- Conclusions

Conclusions

1. Material is Suitable for Ultra Lightweight Design of Opto-Mechanical Structures
   - Isotropic Characteristics
   - CTE Compatibility to Coating Materials (SiC, Si, Glass)
   - Easy Shaping of Complex Structures (Design Flexibility)
   - No Shrinking
   - Very Large Pieces by Joining
   - No Open Porosity
   - High Stiffnes, High Strength
   - Short Manufacturing Process
   - Low Thermal Expansion at High Thermal Conductivity

2. C/SiC is Suitable as Basic Material for Different Proposed NGST Mirror Designs

Mirror Design Concepts

Passive Optics

C/SiC Ultra Light Weight Substrate
with or without coating

Active Optics

Monolithic Mirror
- **C/SiC Ultra Light Weight Substrate**
- **Layer with Electrode Pattern**
- **Layer from PZT/PMN Ceramics**
- **Glass Layer (Polished like Monolithic Optics)**

Stacked Facesheet Mirror
- **Support Structure Designed in C/SiC**
- **Dicrete PZT Stacks or Actuators**
- **Glass Face**

Both Mounted on Global Positioning Actuators on Deployable Structure

Requirements

Advanced Composite Materials for Opto-Mechanical Applications:

- **Low Density**
- **Low Thermal Expansion**
- **High Stiffness**
- **High Strength**
- **Appropriate Thermal and Electrical Conductivity**
- **High Quality Optical Surfaces**
- **Flexible Design and Up-Scaling Capability**

Our Solution

C/SiC - Randomly Oriented Chopped Carbon Fibre Reinforced Silicon Carbide Structures with Polishible or Oxidation Protected Coatings Manufactured by:

- **Green Body Machining of C/C Raw Materials with Low Density and Randomly Orientated Chopped Carbon Fibre Reinforcement**
- **Infiltration Processing (without any Shrinkage) of C/C Structures with Pyrolytic Carbon and Liquid Silicon, Partly Reacted to SiC**
- **CVD-Deposition of Polishable or Oxidation Protective Coatings (e.g. Silicon Dioxid, Silicon Carbide, Glass) on the C/SiC Substrate Surface**
- **C/SiC Reveals a Variety of Optomechanical, Thermomechanical, Thermo-environmental and Configuration Aspects, which "Classical" Materials Like Metals, Glass or other Ceramics can not Provide Completely**
- **State of the Art Facilities Allow C/SiC Processing of Components with Diameters up to 3.0 Meter**

C/SiC Material Characteristics/Properties (1)

- Composition SiC : Si : C 50-60 % : 20-30 % : 10-20 % (typical value)
- Low Specific Density (2,6 - 2,7 g/cm◊)
- Tunable Stiffness (240-260 GPa) and Strength (140-210 MPa)
- Low Coefficient of Thermal Expansion [CTE], (20 °C-1000 °C : 1,8- 4,1 x 10^{-6} K^{-1})
- High Thermal Conductivity and Diffusion (~ 135 W/mK)
- Low Electrical Resistance (~ 200 x 10^{-6} Ohm x m)
- Isotropic Material Properties and Characteristics
- Resistance to Corrosion/Oxidation and Abrasion
- High Hardness (> 1500 N/mm∆)
- High Temperature Resistance (~ 2100 °C, Air), Optical Applications: ~ 1200 °C, Corrosive Applications: ~ 2100 °C

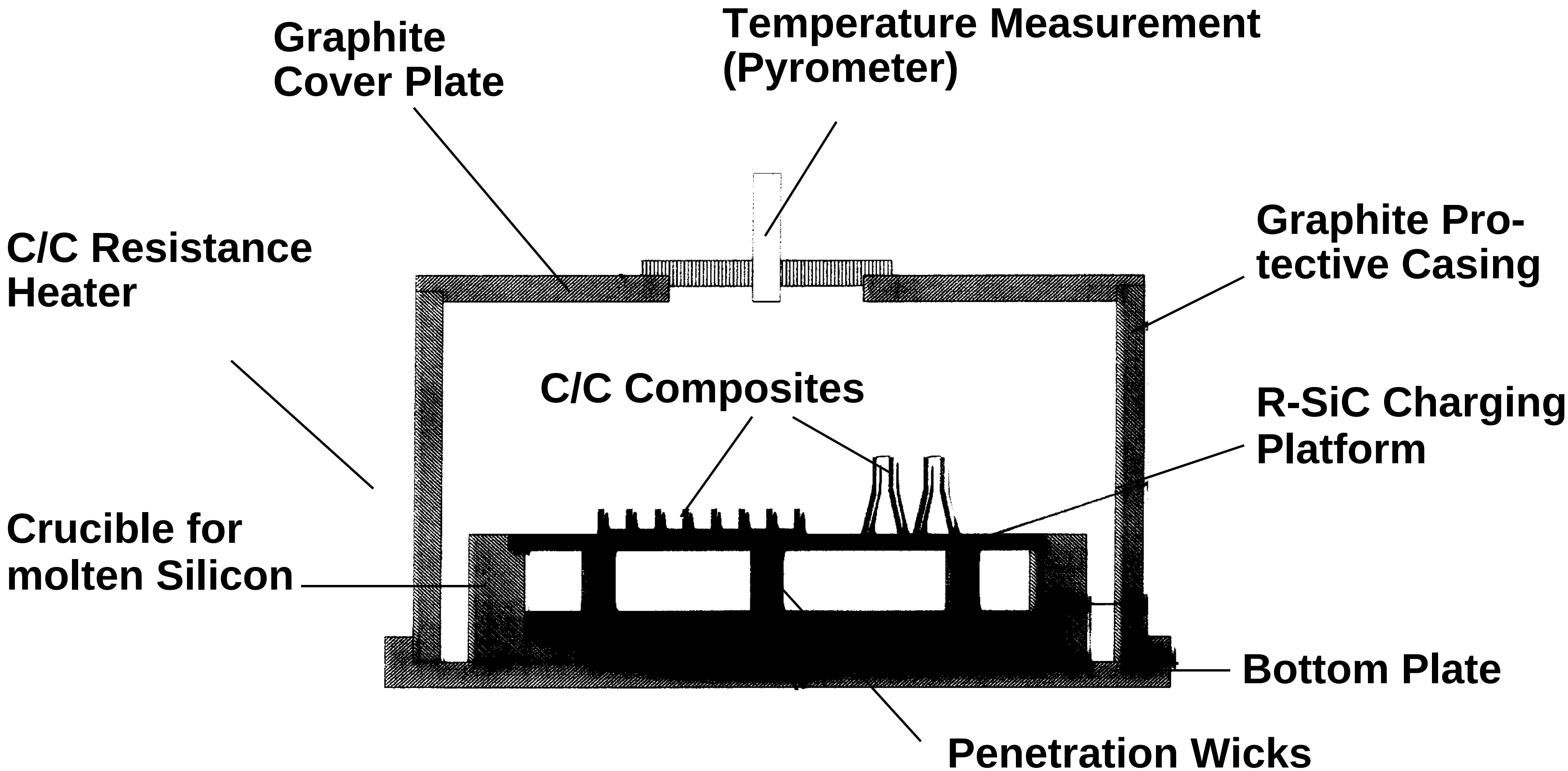
C/SiC Material Characteristics/Properties (2)

- High Thermal Shock Resistance (> 2100 K/sec)
- No Ageing and Creeping Effects (Stability of Shape)
- Non-magnetic
- Bio-compatible
- Damage Tolerance Behaviour
- Fast, Near Net Shape Infiltration Process Without Shrinkage
- Low-Cost Machining, no Special Tools Required
- Flexible Design and Large Structure Up-Scaling Capabilities
- High Quality Optical Surface Layers (e.g. SiC, Glass and Si, Roughness: < 5 A)
- Optimized Application Design Capability Due to the Flexibility of Possible Variations of Material Process Parameters, etc.

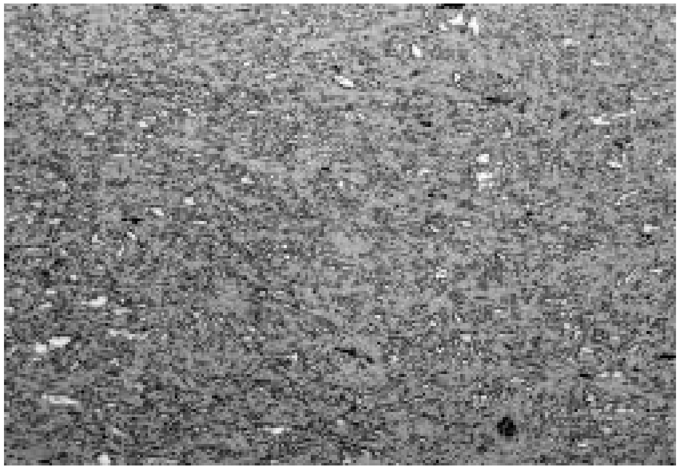
Silicon Infiltration Processing

- Infiltration processing (without any shrinkage) of porous C/C-structures with molten silicon by capillary forces in high temperature vacuum process
- Densification and partial reaction of carbon matrix with silicon to silicon carbide (SiC)
- Processing temperature: 1500-2100 °C
- Processing pressure: < 100 mbar (vacuum)
- Reaction time: 15-60 minutes
- Short manufacturing process (24 hours from cold to cold)
- Near-net-shape infiltration process (minimal pre-grinding) without shrinkage and minimized stress introduction

Silicon Infiltration Process Facility



Material Structure after Infiltration



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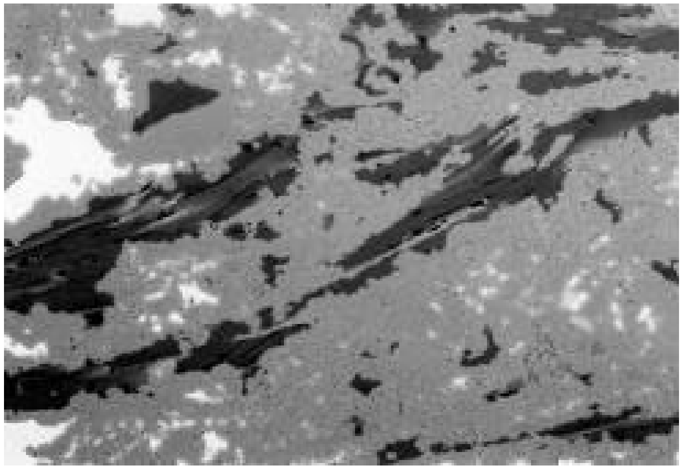

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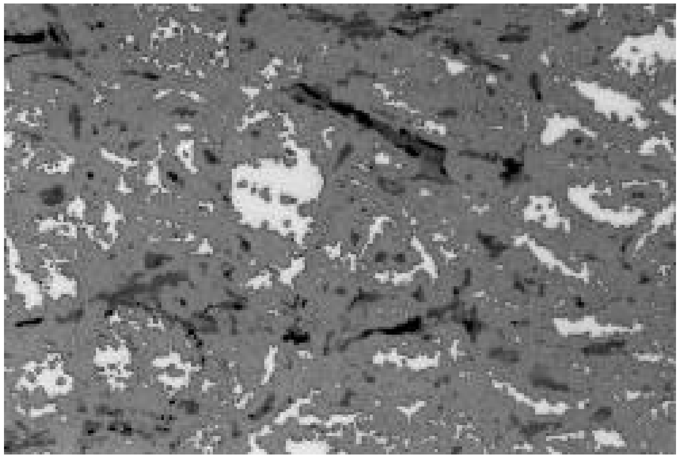


100 x

Controlling & Tailoring of C/SiC-Material Properties

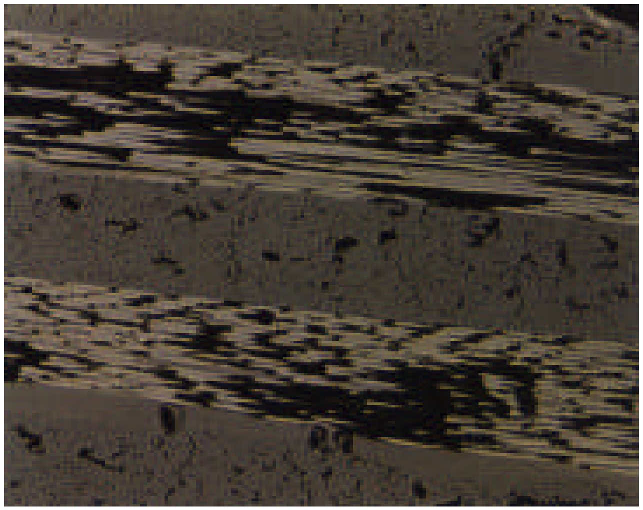
Optimized Application Design Capability due to Flexibility of possible Variations of Material Processes Parameters:

- **Carbon fibre/-matrix content of the C/C raw materials**
- **Density, pore volume and pore sizes of the C/C raw materials**
- **Carbon fibre type, -length, -pretreatment**
- **Carbon matrix forming process (reactivity of the carbon matrix)**
- **Carbon fibre protection systems (preventing chemical reactions, controlling fibre/matrix interface)**
- **Silicon infiltration process parameters (heat treatment, maximum temperatures, duration, pressure)**
- **Thermal treatments (graphitization), etc.**

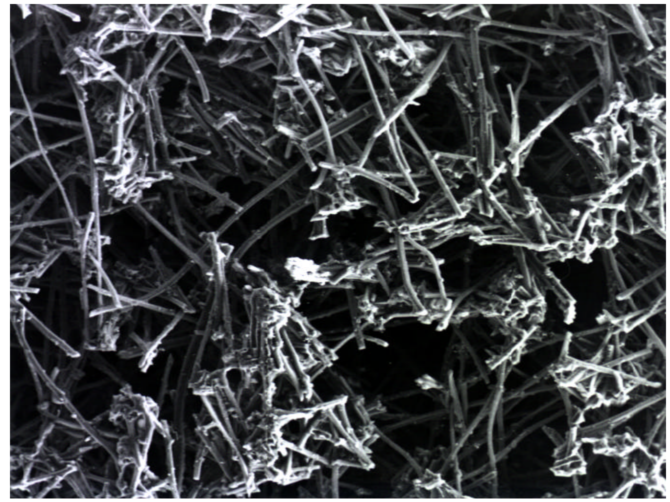
Manufacturing Process of C/SiC-Mirrror Structures

1. Raw Material
   Random oriented chopped C/C-Felt
2. CFRP-Molding
3. Carbonization
   Vacuum, 1000º C
4. Graphitization
   Vacuum, 2100º C
5. Green Body Machining
6. Liquid Silicon Infiltation
   SiC-Reaction, Vacuum 1600º C
7. Pre-Grinding
8. CVD-SiC Reflective Coating
   2 Cycles at 1200º C
9. Optical Polishing
   of reflective Surfaces
10. C/SiC Optical Components

CMC-Composites with Continuous (2-D) and Short Carbon Fibre Reinforcement



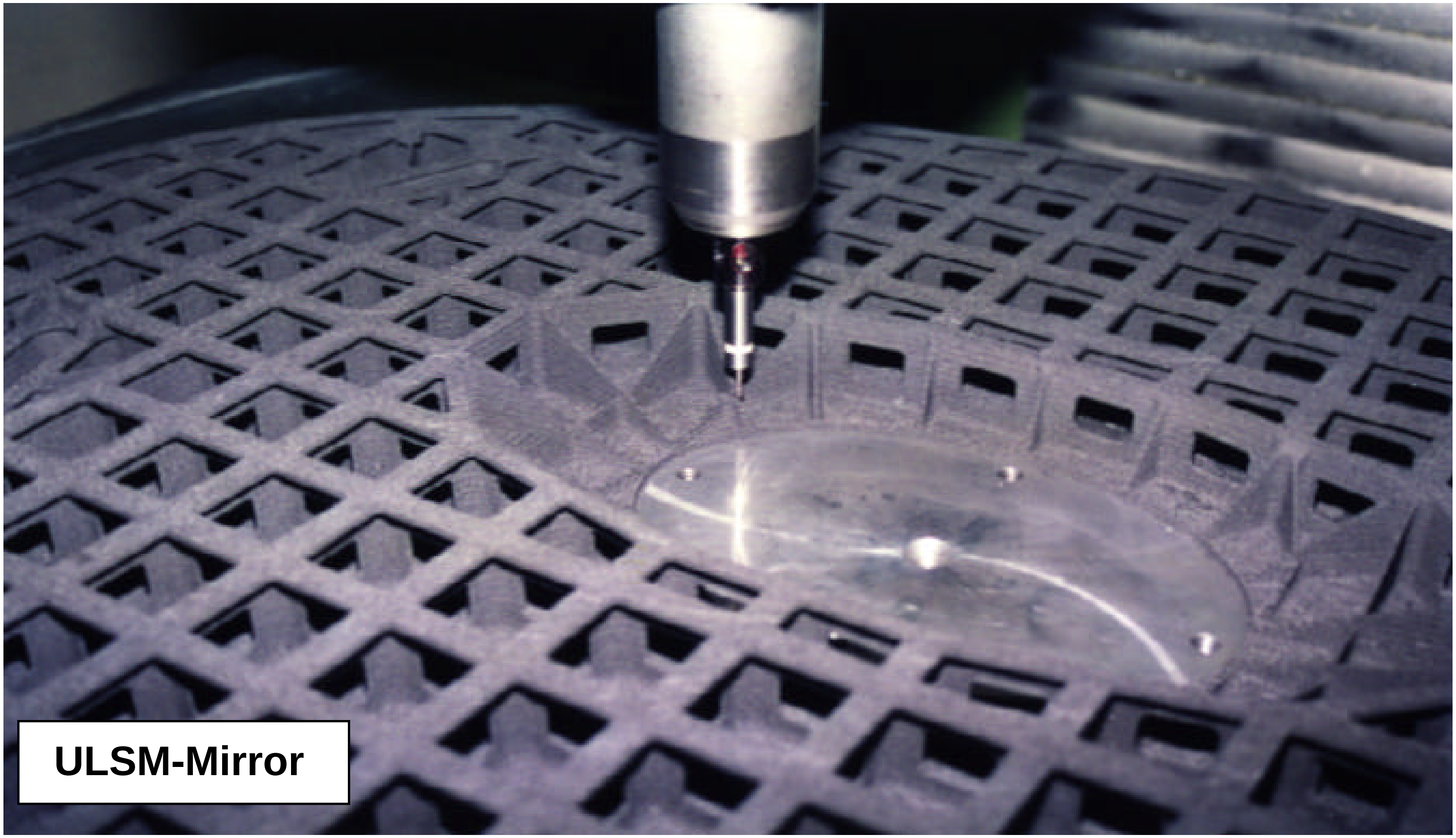
Continuous (2-D) Reinforcement



Short Carbon Fibre Reinforcement

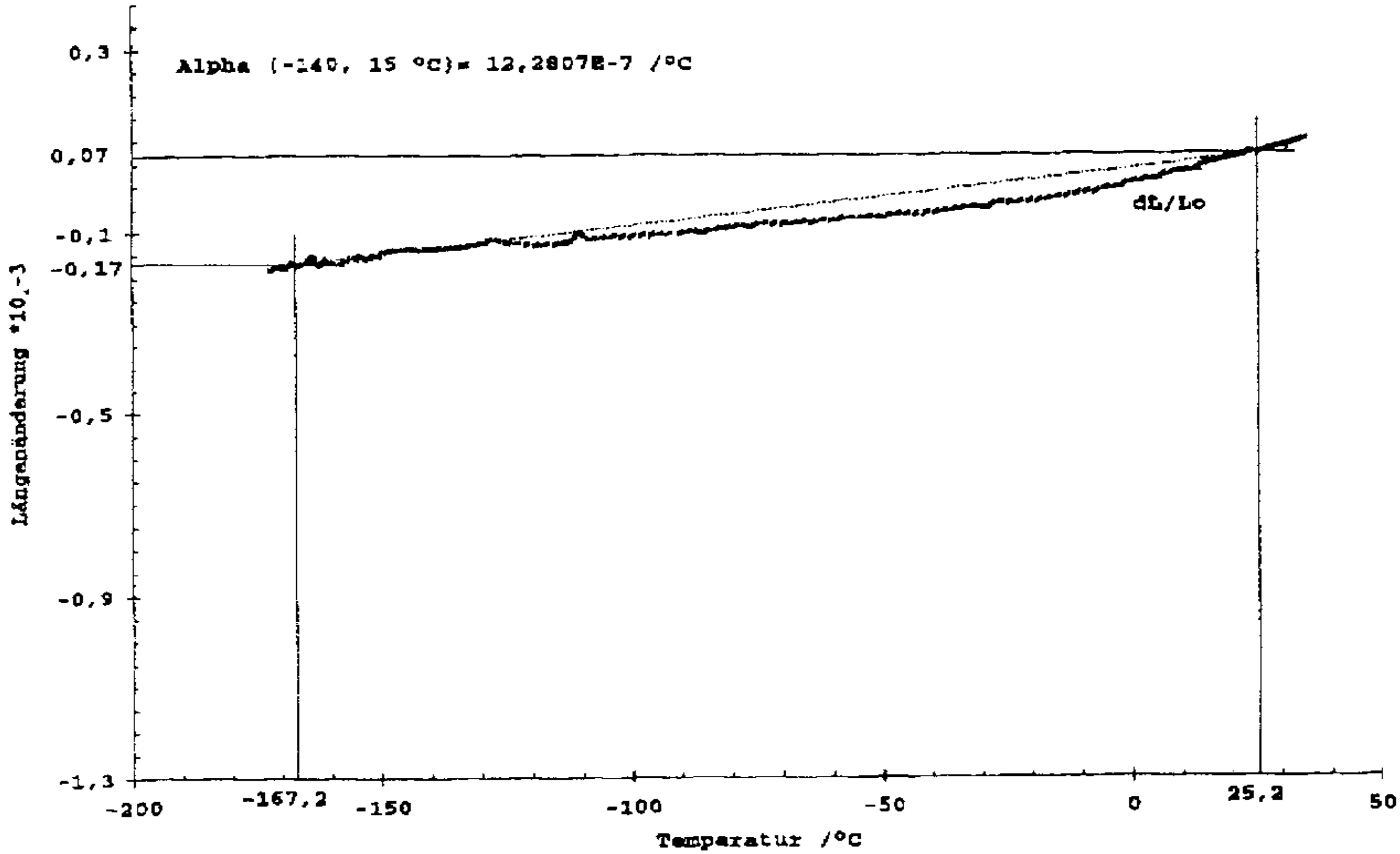
- Carbon Fibres have an Anisotropical Behaviour Concerning Strength, Stiffness, CTE, Thermal Conductivity and Electrical Resistance
- Continuous Carbon Fibre Reinforcement leads to an anisotropical behaviour in the x-, y- and z-Direction of the CMC Composites
- Short Carbon Fibre Reinforcement (Randomly Oriented Leads to an Isotropical Behaviour in the x-, y- and z-Direction of CMC Composites)

Machining (Milling) of C/C-Felt (Green Body) with Conventional Processing Machines to Final Design



ULSM-Mirror

CTE Behaviour of C/SiC
Range: - 167 °C (110 K) to + 25 °C (303 K)



Tensile Tests With C/SiC at 20 °C, Stress Versus Strain

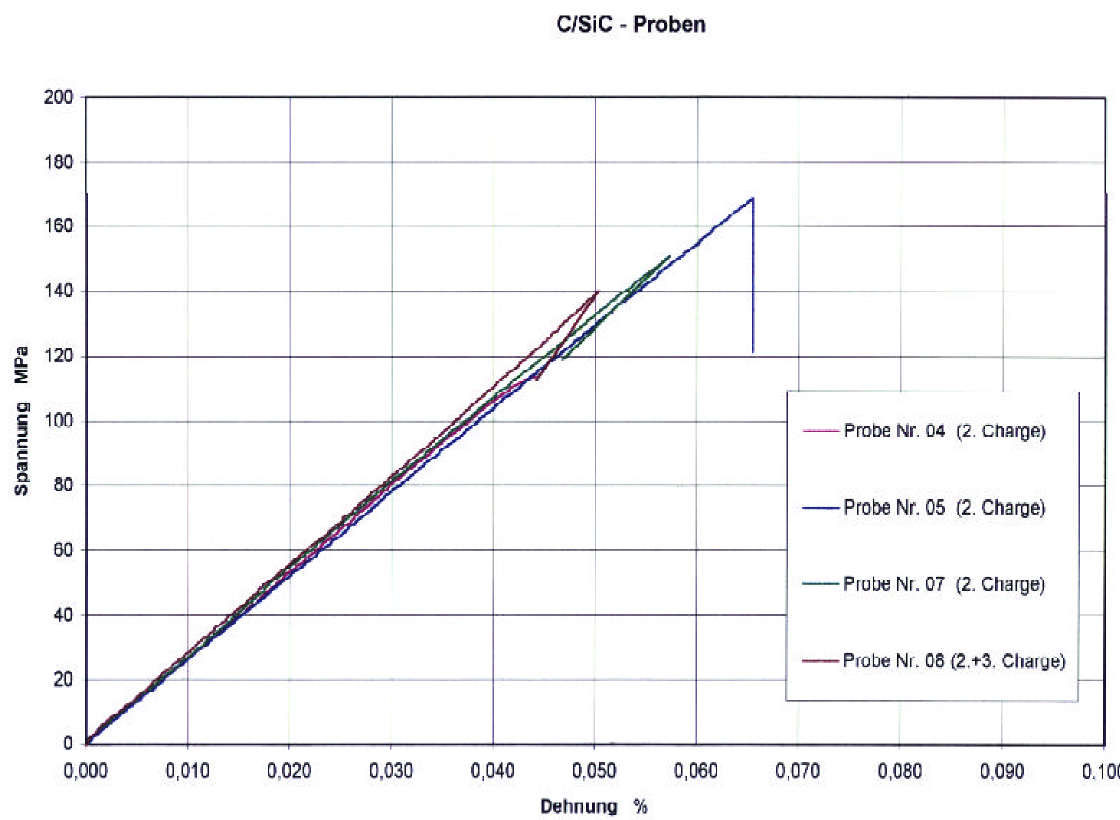
Density:
2.65 g/cm◊

Tensile Strength:
140 MPa

Tensile Modulus:
260 GPa

Bending Strength:
210 MPa

Bending Modulus:
235 GPa



Tensile Tests With C/SiC at 20 °C, Stress Versus Strain

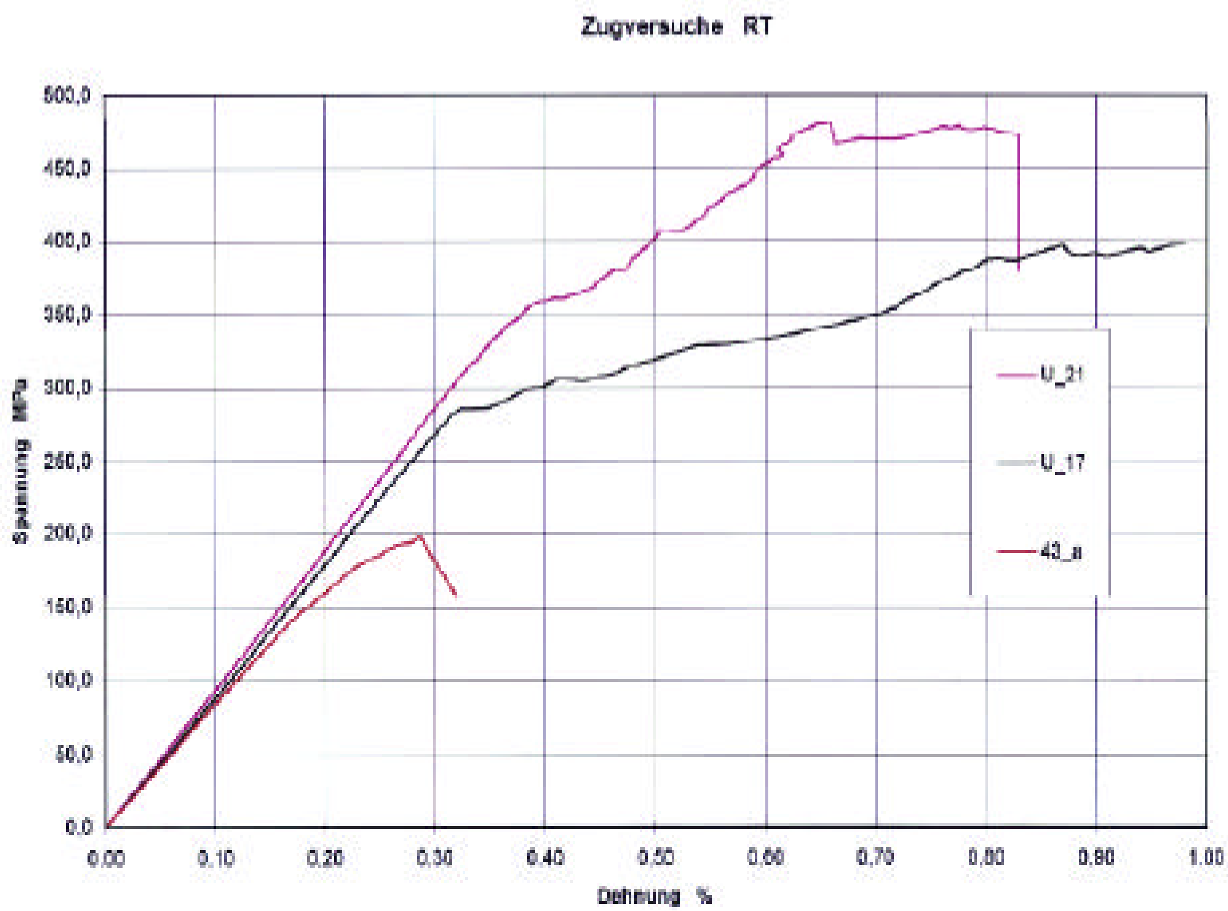
Density:
1,5 g/cm◊

Tensile Strength:
480 MPa

Tensile Modulus:
90 GPa

Bending Strength:
300 MPa

Bending Modulus:
85 GPa

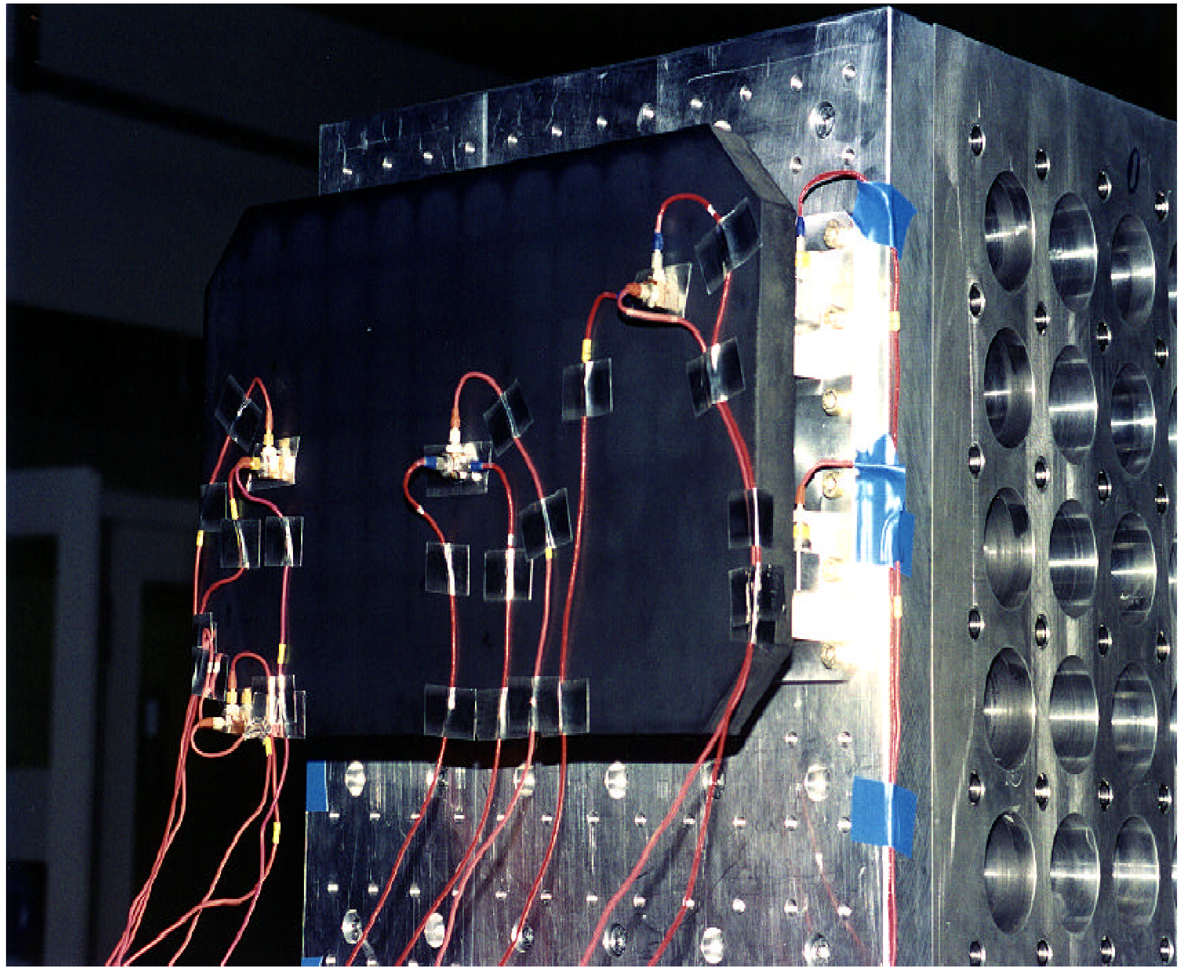


Shaker Vibration Test of Lightweight C/SiC Mirrors

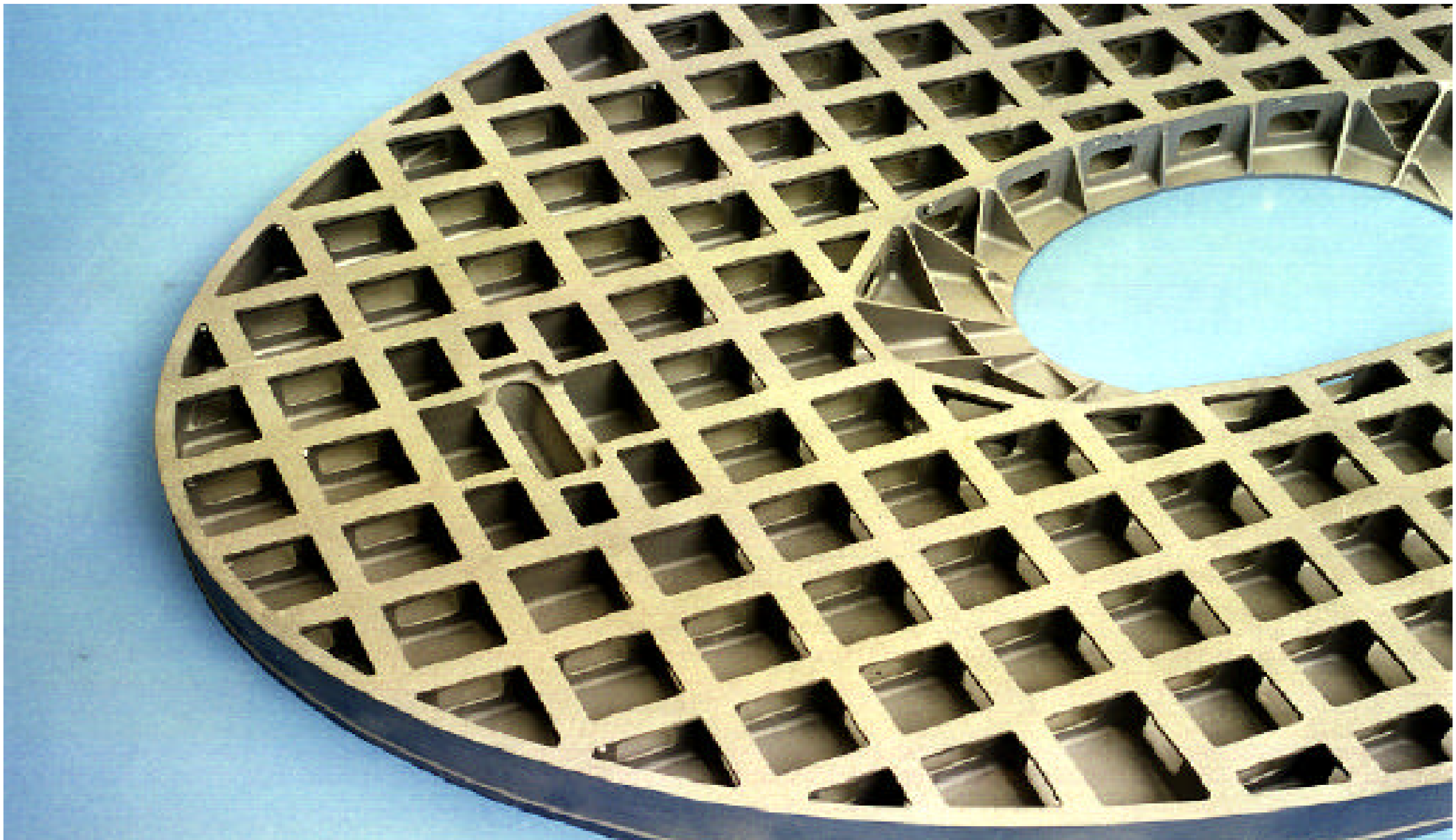
45 g Loading in x-, y- and z-Direction

Mirror Dimension:
480 x 280 x 40 mm◊

Mirror Mass:
4 kg



Ultra-lightweight structure (rear side) of MSG C/SiC Scan Mirror



C/SiC Scan Mirror Test Article

Dimensions:
480 x 280 x 40 mm◊

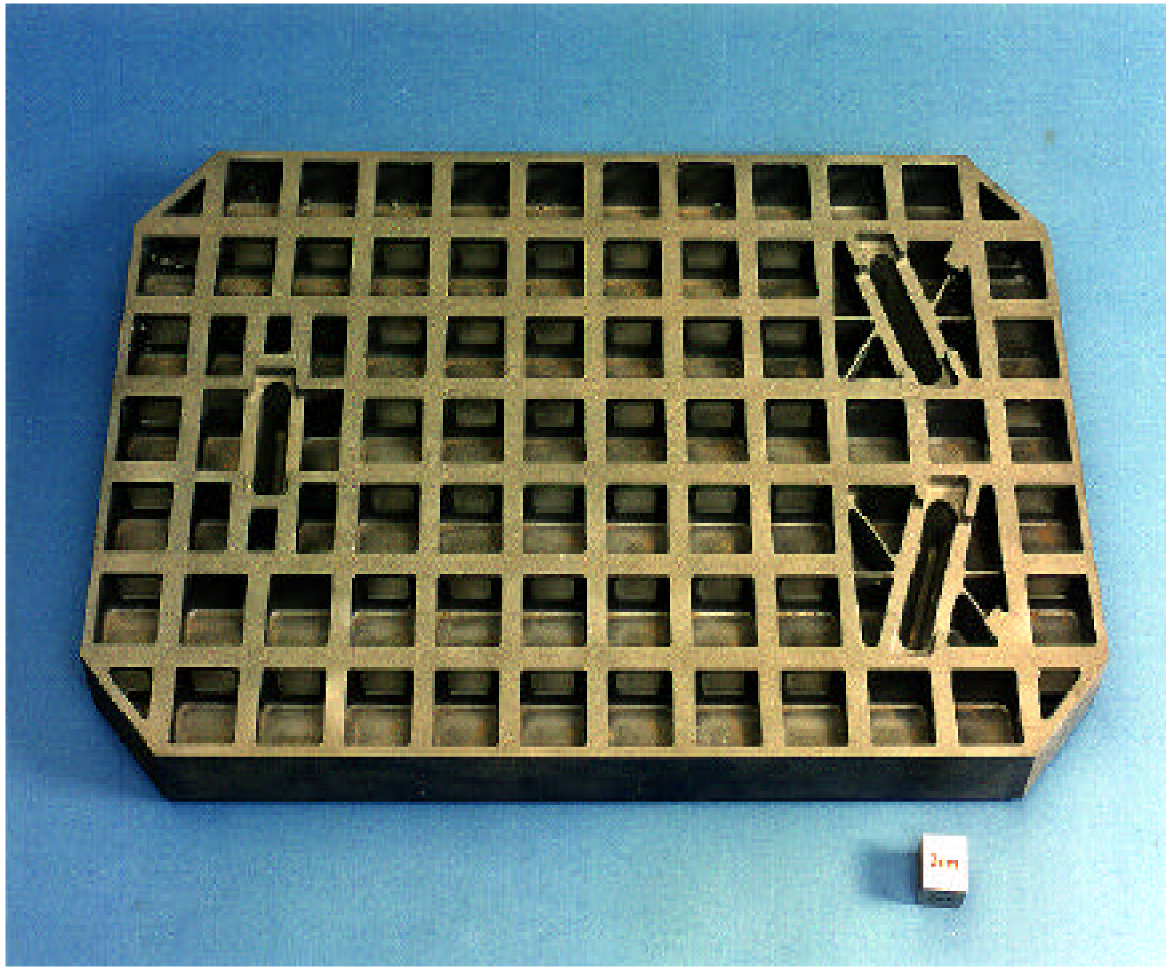
Mass: 3 kg

First Eigenfrequency:
210 Hz

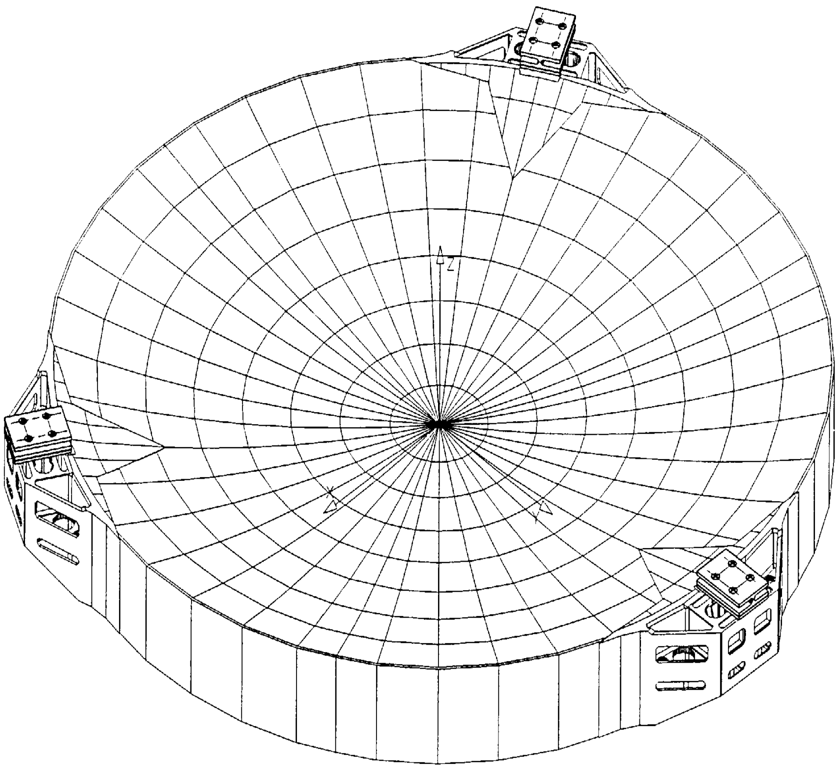
Used for Testing:

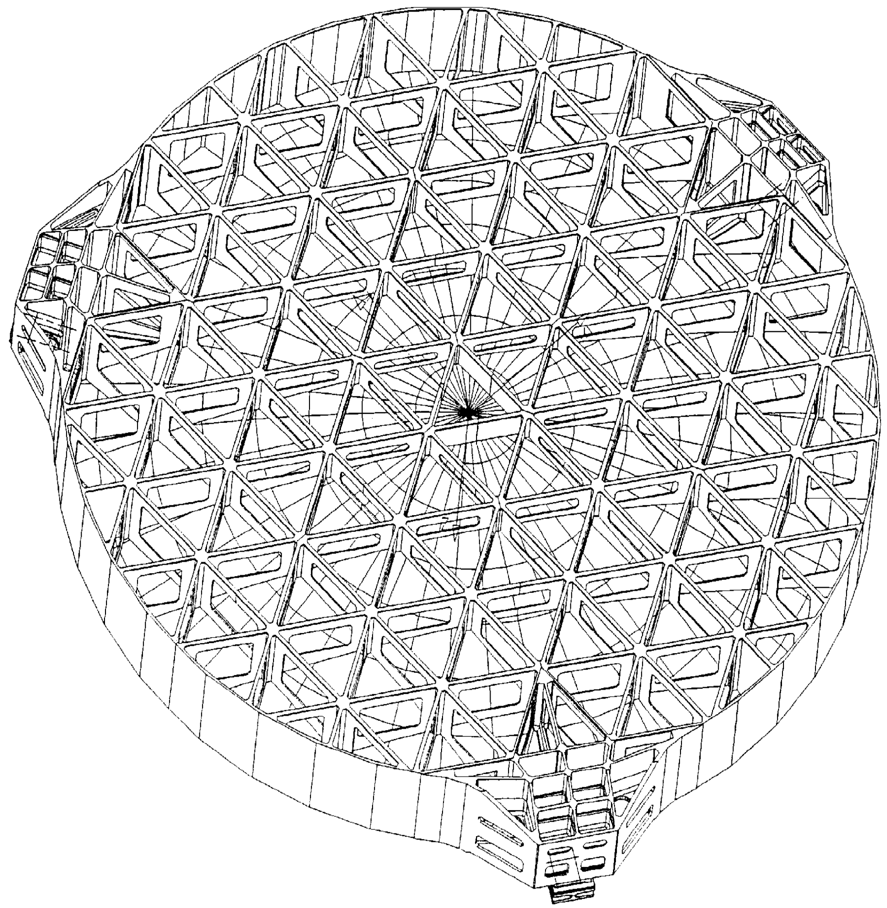
- **Thermal**
- **Mechanical**
- **Environmental**

With SiC-Coating on Rear Side



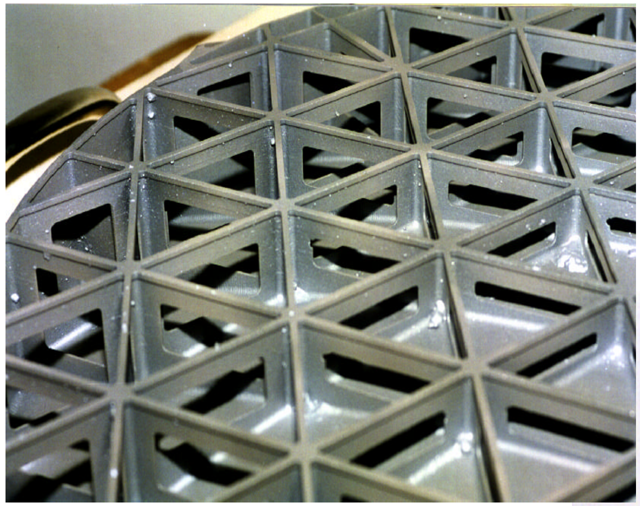
ATLID Telescope Mirror Design Based on C/ SiC



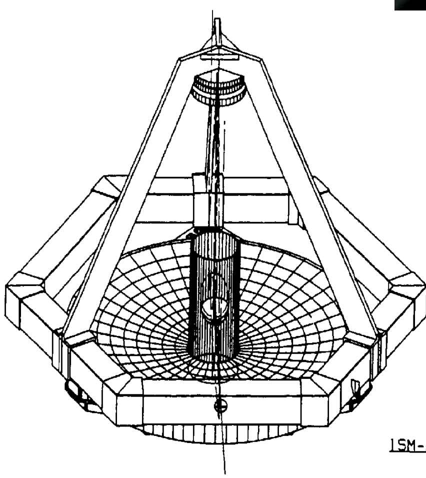


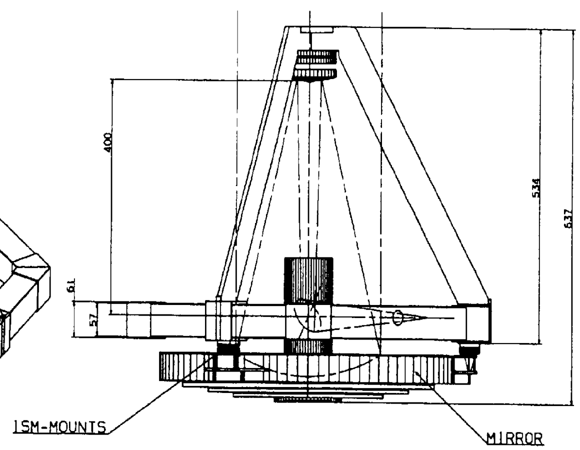
C/SiC ATLID Telescope Primary Mirror

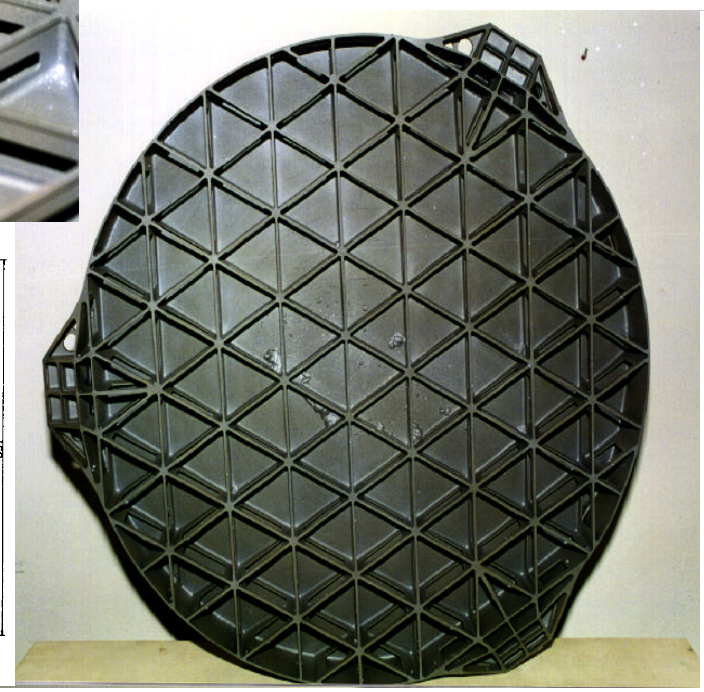
Diameter: 630 mm
Mass: 6,0 kg (incl. coating and mounting prov.)
Rim Height: 70 mm
Rib Thickness: 1 mm
Parabolic F=0,9
Areal Weight =19,24 Kg/m^2



- **Lightweighting 12 % (with resp. to solid dimensions)**
- **First Eigenfrequency 424 Hz**
- **Integrated Mounting Provision**

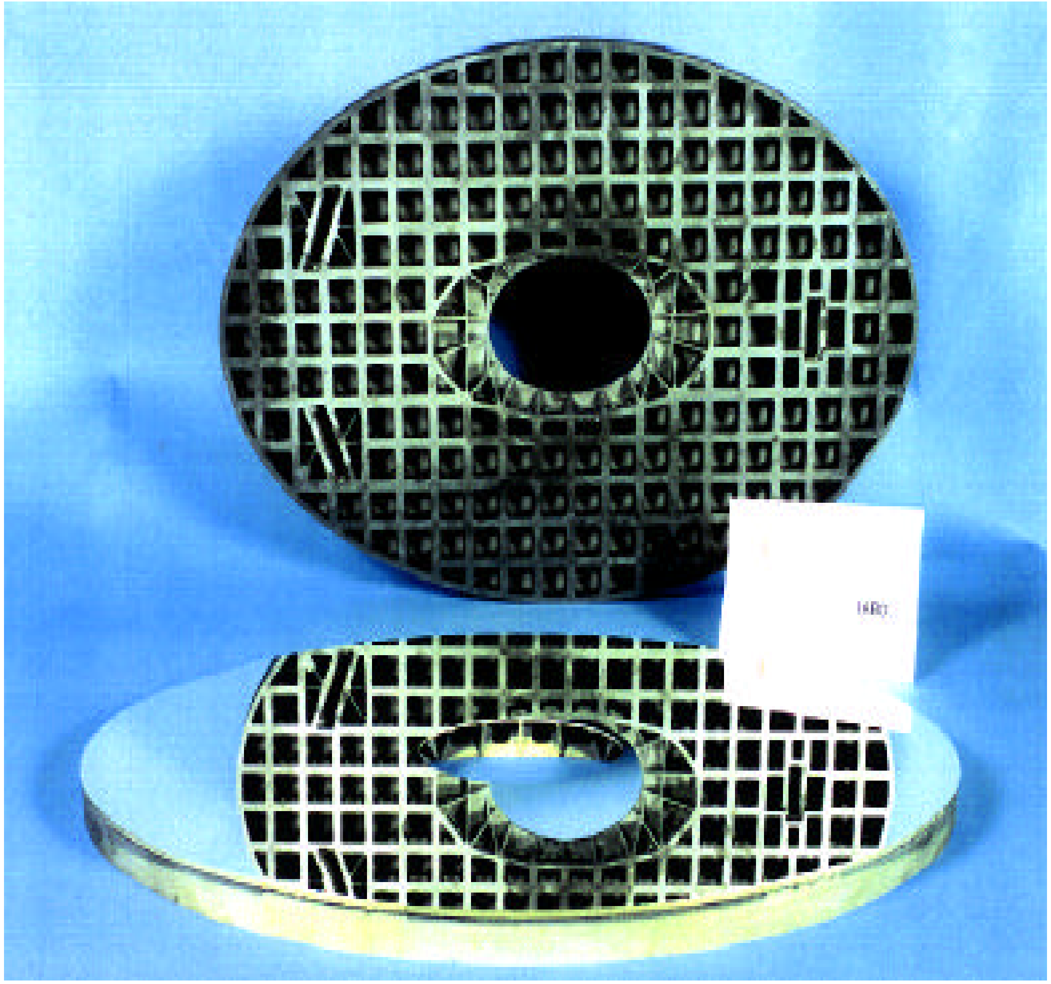






MSG C/SiC Scan Mirror

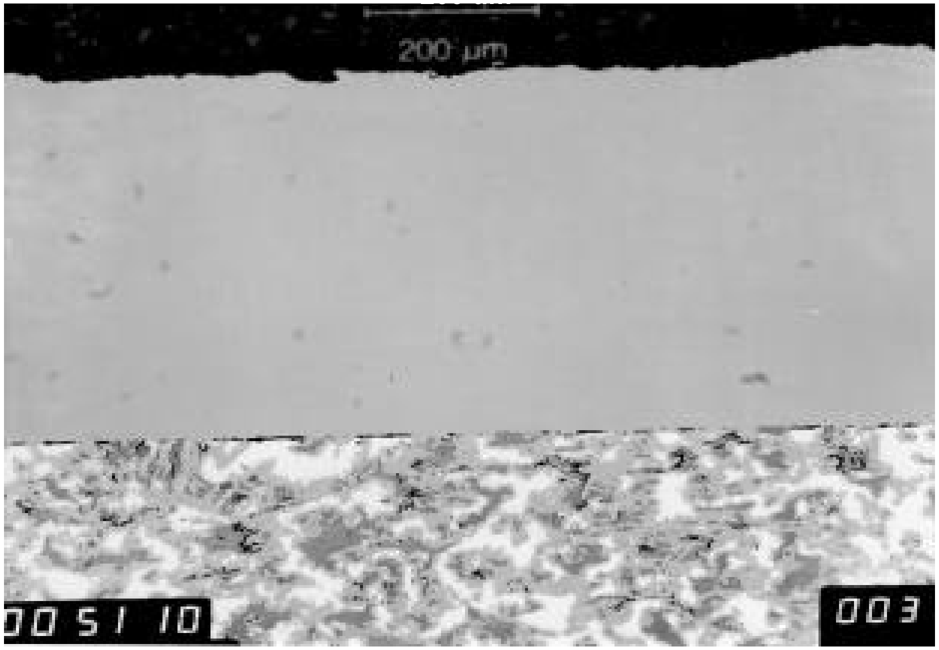
Dimensions:
 805 x 520 x 40 mm◊
 180 x 140 (center hole)
Mass: 8 kg
Areal Weight:
 25,89 kg/m°2
Micro-Roughness:
 < 10 Angström
Optical Surface Quality:
 lambda/6
First Eigenfrequency:
 400 Hz



Coated with CVD-SiC and Silver
Optically Polished
View from Front and
Rear Side

Polishible Coating

- Si or SiC-Coating



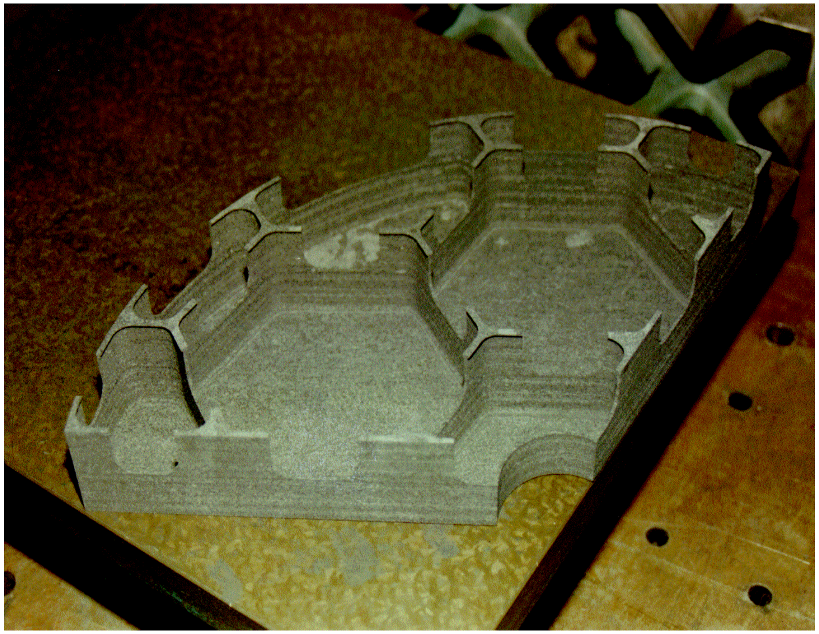
CVD-SiC-Coating of C/SiC

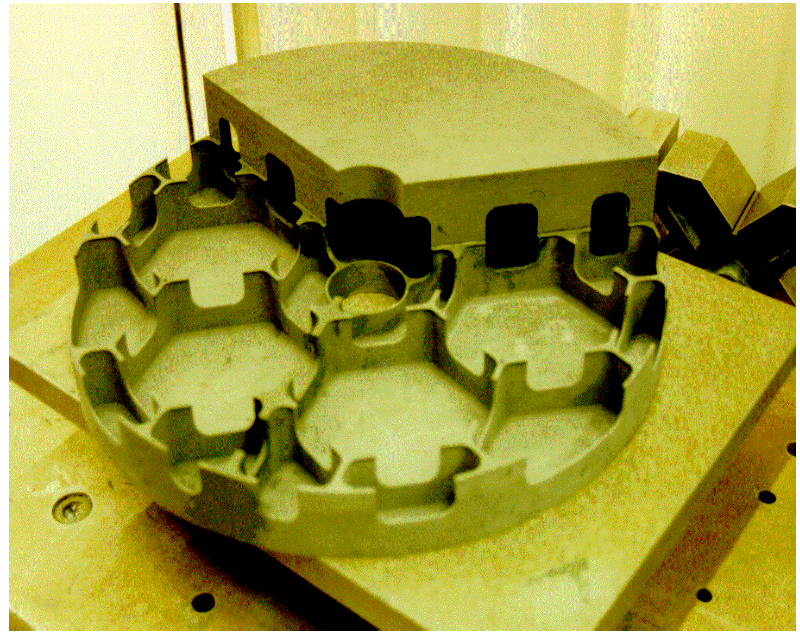
No Cracks due to CTE-compatibility

- Glass Coating

Hot Pressing of Glass Sheet on C/SiC Mirror Substrate

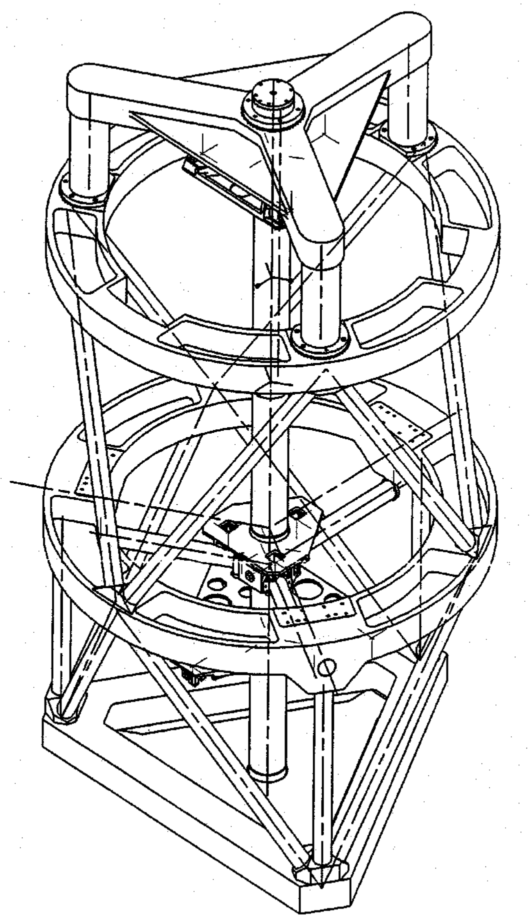
Joining Techniques



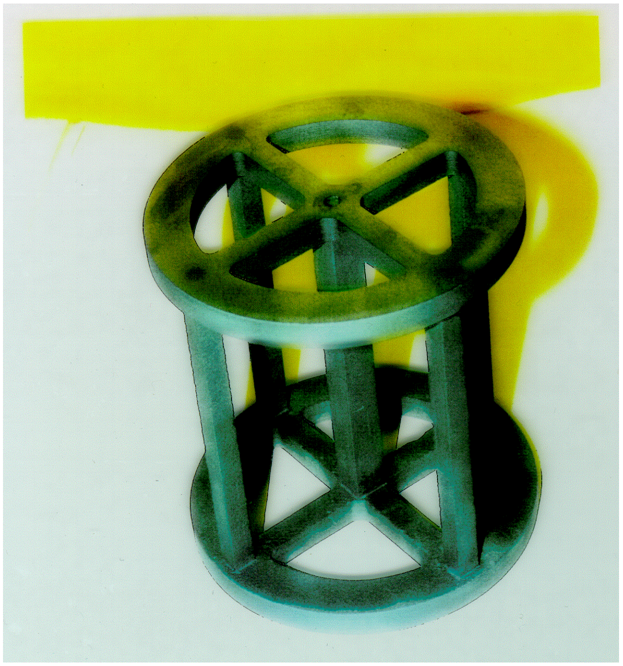


- ❑ Assembling of Parts (max. Size 200 x 200 x 20 cm) by Mechanical Fittings or Screws
- ❑ Fixation by Phenolic Fibre Resin Clou
- ❑ Converted to Carbon During Infiltration
- ⇨ Homogenuous Material Texture at Joining Areas

A-Thermal Design of Complex Telescope Structures



Optical Bench Actually in Manu-facturing Size:260X150 cm



Test Article for Lab Tests of Stability During Thermal Cycling

Thermal Performance

Thermal Figures of Merit:

			C/SiC	Zerodur	Be I-70A
CTE @ RT	α	10^{-6} K^{-1}	2,0	0,05	11
Thermal conductivity	k	W / m K	135	1,64	194
Specific heat	c	J / kg K	700	821	1820
Young's Modulus	E	GPa	260	90,6	289
Steady state thermal distortion	E k / α		17.550	2.972	1.598
Dynamic thermal distortion	E k / (α c)		25,07	3,62	2,80

Thermal Performance may be Influenced by Design and Manufacturing such as

- **Surface Treatment**
- **Lightweighting Ratio**
- **Seeing Factors**
- **Heat Conducting Cross Sections**